

Possible existence of E_p – L_p and E_p – E_{iso} correlations for Short Gamma-Ray Bursts with a factor 10 to 100 dimmer than those for Long Gamma-Ray Bursts.

Ryo Tsutsui^{1*}, Daisuke Yonetoku²

Takashi Nakamura³, Keitaro Takahashi⁴, and Yoshiyuki Morihara²

¹Research Center for the Early Universe, School of Science, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan

²Department of Physics, Kanazawa University, Kakuma, Kanazawa, Ishikawa 920-1192, Japan

³Department of Physics, Kyoto University, Kyoto 606-8502, Japan

⁴Faculty of Science, Kumamoto University, Kurokami, Kumamoto, 860-8555, Japan

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ABSTRACT

We analyzed correlations among the rest frame spectral peak energy E_p , the observed frame 64ms peak isotropic luminosity L_p and the isotropic energy E_{iso} for 13 Short Gamma Ray Burst (SGRB) candidates having the measured redshift z , $T_{90}^{\text{obs}}/(1+z) < 2$ sec and well determined spectral parameters. A SGRB candidate is regarded as a misguided SGRB if it is located in the 3σ region from the best fit function of the E_p – E_{iso} correlation for Long GRBs (LGRB) while the others are regarded as secure SGRBs possibly from compact star mergers. Using 8 secure SGRBs out of 13 SGRB candidates, we tested whether E_p – E_{iso} and E_p – L_p correlations exist for SGRBs. We found that E_p – E_{iso} correlation for SGRBs ($E_{\text{iso}} = 10^{51.42 \pm 0.15} \text{ erg s}^{-1} (E_p/774.5 \text{ keV})^{1.58 \pm 0.28}$) seems to exist with the correlation coefficient $r = 0.91$ and chance probability $p = 1.5 \times 10^{-3}$. We found also that the E_p – L_p correlation for SGRBs ($L_p = 10^{52.29 \pm 0.066} \text{ erg s}^{-1} (E_p/774.5 \text{ keV})^{1.59 \pm 0.11}$) is tighter than E_p – E_{iso} correlation since $r = 0.98$ and $p = 1.5 \times 10^{-5}$. Both correlations for SGRBs are dimmer than those of LGRBs for the same E_p by factors $\sim 100(E_p - E_{\text{iso}})$ and $\sim 10(E_p - L_p)$. Applying the tighter E_p – L_p correlation for SGRBs to 71 bright BATSE SGRBs, we found that pseudo redshift z ranges from 0.097 to 2.258 with the mean $\langle z \rangle$ of 1.05. The redshifts of SGRBs apparently cluster at lower redshift than those of LGRBs ($\langle z \rangle \sim 2.2$), which supports the merger scenario of SGRB.

Key words: gamma rays: bursts — gamma rays: observations — gamma rays: short.

1 INTRODUCTION

For Long Gamma Ray Bursts (LGRBs), several observational correlations among the rest frame spectral peak energy E_p , the peak isotropic luminosity L_p and the isotropic energy E_{iso} in the prompt emission phase have been proposed. E_p – E_{iso} correlation was first reported by Amati et al. (2002) and argued by many authors (Sakamoto et al. 2004; Lamb et al. 2004; Amati 2006; Amati et al. 2009; Yonetoku et al. 2010).

As for L_p , Yonetoku et al. (2004) reported a rather tight correlation between E_p and the observed frame 1-second peak isotropic luminosity L_p . In 2004, the number of LGRBs with well determined redshifts and spec-

tral parameters was only 16. Nevertheless, the correlation was found to be very tight: the linear correlation coefficient (r) between $\log E_p$ and $\log L_p$ is 0.958 and the chance probability (p) is 5.3×10^{-9} . Several authors argued on the property of the E_p – L_p correlation (Ghirlanda et al. 2005b,a; Krimm et al. 2009) and confirmed the existence, while Tsutsui et al. (2009) found that adding a new observables T_L , the luminosity time defined by $T_L = E_{\text{iso}}/L_p$, improves the correlation and gave E_p – T_L – L_p correlation. In E_p – T_L – L_p correlation, the systematic error is reduced by $\sim 40\%$ compared with the E_p – E_{iso} and E_p – L_p correlations.

Ghirlanda et al. (2004) applied the E_p – L_p correlation to bright short Gamma Ray Bursts (SGRBs) observed by BATSE without measured redshift. That is, they assumed that SGRBs obey the same E_p – L_p correlation of LGRBs and estimated the pseudo redshifts of SGRBs although

* E-mail: tsutsui@resceu.s.u-tokyo.ac.jp(RT)

no evidence for the existence of the E_p – L_p correlation for SGRBs at that time. They found that the pseudo redshifts are obtained for all selected SGRBs and the distribution is similar to that of LGRBs known at that time. On the other hand, Nakar & Piran (2005); Band & Preece (2005); Butler et al. (2007); Shahmoradi & Nemiroff (2010) argued that E_p – L_p correlation might be due to selection effects, since E_p was determined from the time integrated spectra. However, Ghirlanda et al. (2010) showed that in the individual pulses of several LGRBs, E_p – L_p correlation holds for each pulse even though E_p changes an order of magnitude from pulse to pulse. Similar property was found for GRB061007 by Ohno et al. (2009). These results strongly suggest that E_p – L_p correlation is not a result of selection biases but a real physical one.

As for SGRBs, the number of SGRBs with measured redshifts and E_p was so small that it was difficult to check if E_p – L_p correlation holds or not. However, Ghirlanda et al. (2011) showed that for 14 Fermi/GBM SGRBs without redshifts, the individual pulses follow a relation of $E_p \propto F_{\text{pulse}}^s$ with $s \sim 1$ where F_{pulse} is the observed energy flux. This reminds us what happened to the individual pulses of LGRBs in Ghirlanda et al. (2010) and suggests that a similar correlation might exist even for SGRBs in the rest frame.

In this Letter, we select 13 SGRB candidates with well determined redshift, spectral parameters, E_p , L_p and E_{iso} to see if the correlations among E_p , L_p and E_{iso} exist. In section 2, we will show that our criteria on SGRBs yield 8 secure SGRBs out of 13 SGRB candidates. Using these SGRBs, we examine if the E_p – E_{iso} and E_p – L_p correlations exist or not. In section 3, we will apply the E_p – L_p correlation obtained in section 2 to 71 bright BATSE SGRBs without measured redshift to determine the pseudo redshift z . Section 4 will be devoted to discussions. Throughout the paper we adopt a cosmological model with $\Omega_\Lambda = 0.7$, $\Omega_m = 0.3$ and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

2 SGRBS WITH WELL DETERMINED REDSHIFT z , E_p , L_p AND E_{iso}

In the previous works, it has been checked whether SGRBs are consistent with the E_p – E_{iso} and E_p – L_p correlations for LGRBs. First, Amati (2006) showed that two short GRBs are clear outliers of the E_p – E_{iso} correlation. Then, Ghirlanda et al. (2009) also found that their six SGRBs are inconsistent with the E_p – E_{iso} correlation, while they possibly follow the E_p – L_p correlation. However, by the end of 2011 there are more than 10 SGRBs which have well-determined redshifts and spectral parameters so that we now can check if SGRBs have their own correlations among E_p , L_p and E_{iso} .

Table 1 shows our list of SGRB candidates which are selected as GRBs with $T_{90}^{\text{rest}} = T_{90}/(1+z) < 2$ s following Gruber et al. (2011), rather than $T_{90} < 2$ s. The list contains the redshift z , the rest frame duration T_{90}^{rest} , the spectral peak energy E_p , the peak luminosity L_p in 64 ms of the observer-frame time bin, the isotropic energy E_{iso} , class of SGRB candidates which will be explained later, and the reference. To make Table 1, we collected all GRBs by the end of 2011 with the value of $T_{90}^{\text{rest}} < 2$ s, the measured redshift z , the spectral peak energy E_p , the peak flux $F_{p,\text{obs}}$

and the fluence S_{obs} within the energy range between E_{min} and E_{max} of each instrument. In order to obtain tighter correlations, the time bin of F_p , and then L_p , should be defined in the time in GRB rest frame as discussed in Tsutsui et al. (2011, 2012) for LGRBs. However, the number of SGRBs is so small to determine the best time bin of L_p that we adopt here 64 msec in the observer frame for all SGRBs candidates.

For GRBs detected by Fermi/GBM (090423, 090510, 100117A, 100206, 100816A), we analyze the spectrum with the software package RMFIT¹ (version 3.3rc8) and the GBM Response Matrices v1.8, following the guidance of the RMFIT tutorial². For the other GRBs, we obtained the data from the reference in Table 1. From these spectral parameters, peak fluxes and fluences, we can calculate the bolometric isotropic energy E_{iso} and the peak luminosity L_p between the energy range of 1–100,000 keV in GRB rest frame using the Band function (Band et al. 1993). Although in most of previous works, L_p and E_{iso} between 1–10,000 keV were adopted, in this paper we adopt 1–100,000 keV range, because 090510 has $E_p \sim 8,000$ keV. L_p between 1–100,000 keV of GRB 090510 is 5 times larger than that of between 1–10,000 keV. For 090424, 050709, 051221, 061006, 070714B, 071020, 080913, 100117A and 101219A, we used fixed high energy photon index as $\beta = -2.25$, because we can not obtain high energy photon index due to the lack of number of photons. For short GRBs with extended emission, E_p and E_{iso} were estimated for initial short/hard spikes.

Here we defined SGRB candidates as GRBs with $T_{90}^{\text{rest}} < 2$ s. These are "candidates" because there might be some contamination from LGRBs with relatively short duration (Zhang et al. 2009; Levesque et al. 2010; Lü et al. 2010). Zhang et al. (2009) proposed multiple observational criteria from their physical motivations, such as supernova (SN) association, specific star formation rate (SFR) of the host galaxy, the location offset from the host galaxy, the duration, the hardness and the spectral lag, etc. However, because most of these observational properties are not available in many cases, these criteria are not so useful in practice. In this Letter, we adopt much simpler criteria by Lü et al. (2010) which utilize the E_p – E_{iso} correlation for LGRBs as a discriminator against SGRBs. Thus, we define GRBs which have $T_{90}^{\text{rest}} < 2$ s and are consistent with E_p – E_{iso} correlation for LGRBs within $3\text{-}\sigma$ level as "misguided SGRBs" and the others as "secure SGRBs". That is, if a SGRB candidate is not consistent with the E_p – E_{iso} correlation for LGRBs, we regard it as a secure SGRB.

Figure 1 shows the E_p – E_{iso} (left) and E_p – L_p (right) diagrams for both SGRB candidates in this Letter and LGRBs from Yonetoku et al. (2010). In the left of Fig. 1, the best fit function and $3\text{-}\sigma$ region of E_p – E_{iso} correlation for LGRBs are indicated by the black solid and dotted lines, respectively. A misguided SGRB which is located within $3\text{-}\sigma$ region of the E_p – E_{iso} correlation for LGRBs is marked by a green filled circle, while a secure SGRB by a red filled square. We can see that the secure SGRBs are always under the best fit function of E_p – E_{iso} correlation for LGRBs although it can be above it from our definition of the secure SGRB. This suggests that E_p – E_{iso} correlation might exist

¹ <http://fermi.gsfc.nasa.gov/ssc/data/analysis/>

² http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/vc_rmfittutorial.pdf

even for secure SGRBs. In the left of Fig. 2 we plot only misguided (green filled circle) and secure (red filled square) SGRBs in E_p-E_{iso} diagram. The red solid line is the best fit function of E_p-E_{iso} correlation for secure SGRBs given by

$$E_{\text{iso}} = 10^{51.42 \pm 0.15} \text{ erg s}^{-1} \left(\frac{E_p}{774.5 \text{ keV}} \right)^{1.58 \pm 0.28}. \quad (1)$$

The logarithmic correlation coefficient (r) is 0.91 with the chance probability (p) of 1.5×10^{-3} and the systematic error of 0.39 in logarithm. The dotted red line shows the $3-\sigma$ error. Since the p is small, we can say that E_p-E_{iso} correlation exists for secure SGRBs also. Therefore although it is correct that SGRBs do not obey E_p-E_{iso} correlation for LGRBs, which has been claimed, they do obey the different E_p-E_{iso} correlation with almost the same power law index but a factor ~ 100 smaller amplitude in E_{iso} .

Now let us discuss E_p-L_p correlation. In the right of Figure 1, we plot misguided (green filled circle) and secure (filled square) SGRBs in E_p-L_p diagram. The best-fit function and $3-\sigma$ region of E_p-L_p correlation for LGRBs from Yonetoku et al. (2010) are indicated by the black solid and dotted lines, respectively. We can see that all secure SGRBs are located under the black solid line. This result is nontrivial because the definition of secure SGRBs is based on the E_p-E_{iso} diagram. This fact implies the existence of E_p-L_p correlation for secure SGRBs although all the secure SGRBs are within the $3-\sigma$ errors of E_p-L_p correlation for LGRBs. In the right of Figure 2 we plot only misguided (green filled circle) and secure (filled square) SGRBs in E_p-L_p diagram. It is clear that secure SGRBs have their own correlation and the best-fit function is given by,

$$L_p = 10^{52.29 \pm 0.066} \text{ erg s}^{-1} \left(\frac{E_p}{774.5 \text{ keV}} \right)^{1.59 \pm 0.11} \quad (2)$$

with $r = 0.98$, $p = 1.5 \times 10^{-5}$ and systematic error of 0.13 in logarithm. The dotted red line shows the $3-\sigma$ error. We can say that SGRBs obey E_p-L_p correlation with almost the same power law index but a factor ~ 10 smaller amplitude in L_p . From the value of r and p , we can say that the E_p-L_p correlation for secure SGRBs is tighter than the E_p-E_{iso} correlation for SGRBs. For this reason we use Eq.(2) as a distance indicator in chapter 3 to determine the pseudo redshift of SGRBs without measured redshift.

3 REDSHIFT ESTIMATION

From the analysis in the previous section, the E_p-L_p correlation for SGRBs derived would be a better distance indicator of SGRBs than the E_p-E_{iso} correlation. The best-fit function of Eq. (2) can be rewritten using the observed quantities as

$$\frac{d_L^2}{(1+z)^{1.59}} = \frac{10^{52.29} \text{ erg s}^{-1}}{4\pi F_p} \left(\frac{E_{p,obs}}{774.5 \text{ keV}} \right)^{1.59}, \quad (3)$$

where d_L , $E_{p,obs}$ and F_p are the luminosity distance, the peak energy at the observer's rest frame and the peak flux, respectively. The right hand side of this equation consists of only the observable quantities. Therefore assuming the Λ -CDM cosmology with $(\Omega_m, \Omega_\Lambda) = (0.3, 0.7)$, we can uniquely determine the redshift through the luminosity distance which is a function of redshift. We call this as the pseudo redshift. The important point here is that the left

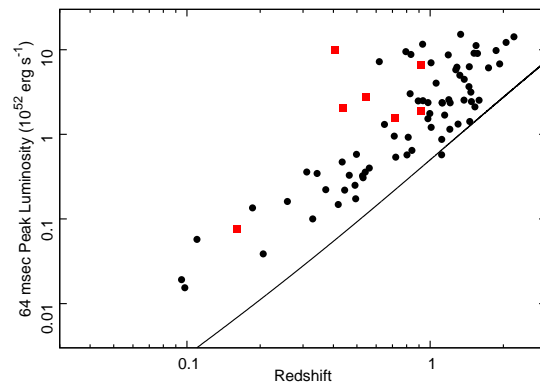


Figure 3. The redshift distribution of SGRBs estimated by the best fit E_p-L_p correlation for SGRBs (Eq.(2)). We used 71 bright BATSE SGRBs reported by Ghirlanda et al. (2009), and succeeded in estimating the redshift for all events. Black dots are the pseudo z and L_p while red filled squares are those of secure SGRBs. Redshift z ranges from 0.097 to 2.581 with the mean $\langle z \rangle$ of 1.05. Note that for *Swift* LGRBs $\langle z \rangle \sim 2.16$ (Jakobsson et al. 2012). The solid line is a reference of flux limit of $F_p = 10^{-6} \text{ erg cm}^{-2} \text{ s}^{-1}$.

hand side of Eq. (3) is a monotonically increasing function of z from zero for $z = 0$ to ∞ for $z = \infty$ so that a unique solution exists for any observed value of the right hand side.

We used the data of 79 bright SGRBs observed by CGRO-BATSE reported by Ghirlanda et al. (2009). The $E_{p,obs}$ values were not measured for 8 samples, so that finally we use 71 samples listed in their list. They selected the events with the burst duration of $T_{90,obs} < 2$ sec and the peak photon flux of $P > 3$ photons $\text{cm}^{-2} \text{ s}^{-1}$ in 64 msec time resolution. They basically used the cutoff power-law (CPL) model to measure the spectral parameters. Using Eq. (3), we can estimate the pseudo redshifts of all 71 SGRBs. In Fig. 3, we show the distribution on the (z, L_p) plane. The solid line is a reference of flux limit of $F_p = 10^{-6} \text{ erg cm}^{-2} \text{ s}^{-1}$. We expect more dim SGRBs under this solid line. We found that the pseudo z ranges from 0.097 to 2.581. The mean pseudo redshift $\langle z \rangle$ is 1.05. We note here that for *Swift* LGRBs $\langle z \rangle = 2.16$ (Jakobsson et al. 2012). In Fig. 2, there are few SGRBs for low z with large L_p . This might be a selection effect since the comoving volume is in proportion to z^3 for $z < 1$ so that the SGRB with large L_p would be rare. For $z > 1$, we do not see such an effect. Although in principle we can determine the luminosity function as in Yonetoku et al. (2004), in practice, the number of SGRBs is too small to do so.

Figure. 3 shows that the pseudo redshift distribution of the bright BATSE SGRBs has a rather sharp cut off around $z = 2.5$. This favors the compact star merger scenario of SGRBs since the time is needed for the binary to merge so that there should be the maximum redshift of SGRBs. Our result seems to be different from the result of Ghirlanda et al. (2004) in which the distribution of pseudo redshifts of SGRBs are similar to that of LGRBs. This is because they assumed the E_p-L_p correlation for LGRBs in Yonetoku et al. (2004). The correlation for LGRBs can be rewritten as $L_p = 10^{53.15} (E_p/774.5)^2$ which is $10^{0.9}$ times brighter than Eq. (2) and then assuming such a bright correlation overestimates pseudo redshifts. We used the corre-

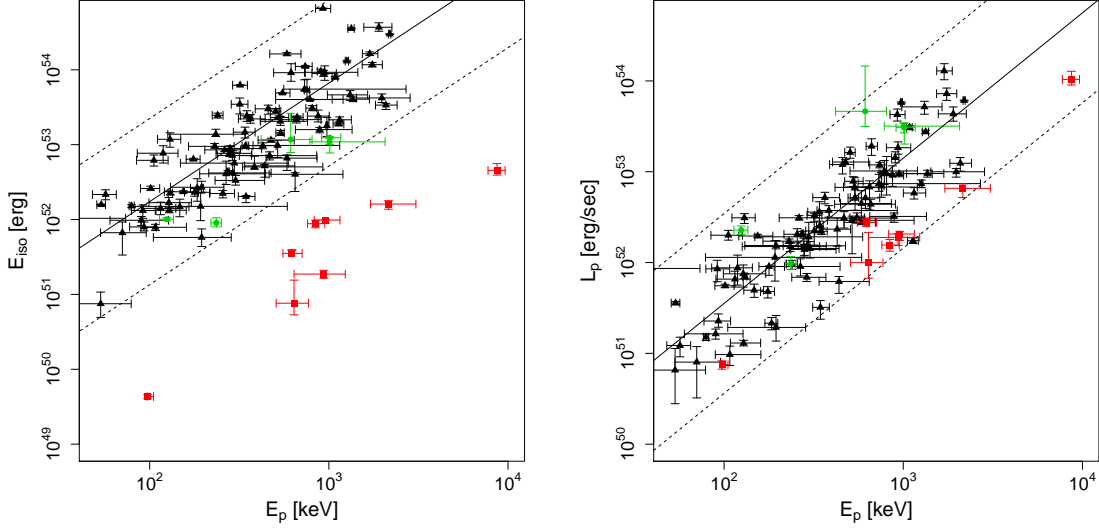


Figure 1. The $E_p - E_{\text{iso}}$ (left) and $E_p - L_p$ (right) diagrams. The LGRBs from Yonetoku et al. (2010) are marked with black filled triangles, misguided SGRBs with green filled circles, and secure SGRBs with red filled squares. The best fit function and $3\text{-}\sigma$ dispersion of the correlations of LGRBs from Yonetoku et al. (2010) are indicated with black solid and dotted lines, respectively. In this figure, the peak luminosities of LGRBs are defined by 1024 msec bin in observer frame, while those of SGRBs are by 64 msec bin in observer frame.

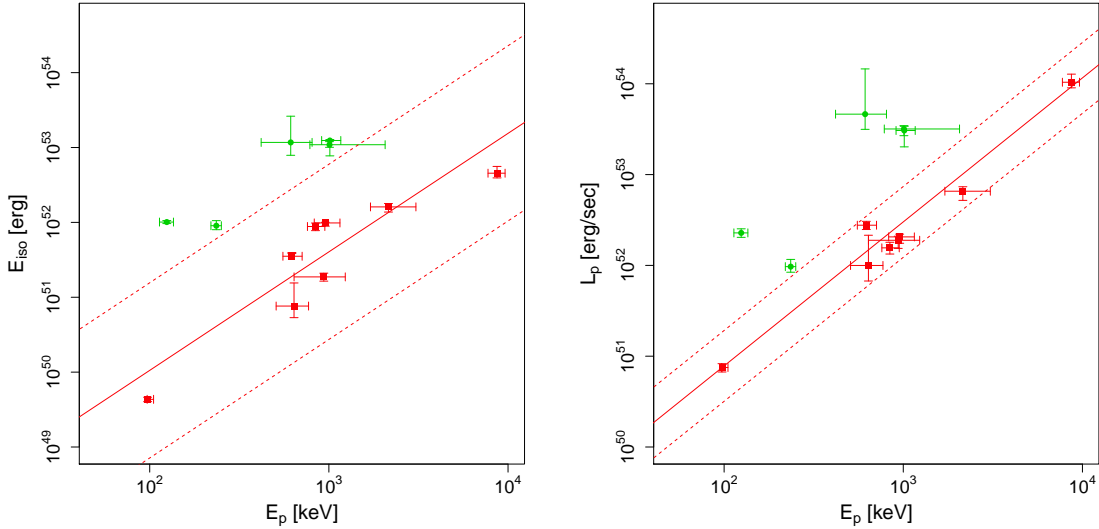


Figure 2. (Left) The $E_p - E_{\text{iso}}$ diagram for SGRBs. (Right) The $E_p - L_p$ diagram for SGRBs. In each figure, misguided SGRBs are marked with green filled circles, and secure SGRBs with red filled squares. The best fit function and $3\text{-}\sigma$ dispersion are indicated with red solid and dotted lines, respectively.

lation constructed with only secure SGRBs, and then our result would be much more reliable.

4 DISCUSSIONS

Recently, Zhang et al. (2012) studied the $E_p - E_{\text{iso}}$ correlation for seven SGRBs, but did not obtain an $E_p - L_p$ correlation for SGRBs themselves. They concluded that short GRBs are consistent with the $E_p - L_p$ correlation for LGRBs. Their seven SGRBs are included in our eight secure SGRBs and our result for the $E_p - E_{\text{iso}}$ correlation seems to be al-

most consistent with their result. Our result for the $E_p - L_p$ correlation, however, seems to be different from their result. In our analysis, the distribution of secure SGRBs in the $E_p - L_p$ diagram is clearly different from that of LGRBs. Although all of secure SGRBs are located in $3\text{-}\sigma$ dispersion region of the $E_p - L_p$ correlation for SGRBs, the best-fit function for SGRBs is different from that for LGRBs ($L_p = 10^{52.97 \pm 0.037} \text{ erg s}^{-1} (E_p / 774.5 \text{ keV})^{1.60 \pm 0.082}$). Figure 4 compares the best-fit parameters and their $1\text{-}\sigma$ uncertainties of the $E_p - L_p$ correlations for LGRBs (black) and SGRBs (red). We assumed the functional form $L_p = 10^A \text{ erg s}^{-1} \times (E_p / 774.5 \text{ keV})^B$ and the values of A and B for

Table 1. List of all SGRB candidates until the end of 2011 used for the analysis. Each column corresponds to the redshift z , the rest frame duration $T_{90}^{\text{rest}} = T_{90}/(1+z)$, the spectral peak energy E_p , the peak luminosity L_p in 64 ms of the observer frame time bin, the isotropic energy E_{iso} , class of SGRB candidates and the reference, respectively. For details see the text.

GRB	redshift	T_{90}^{rest} [sec]	E_p [keV]	L_p [erg/s]	E_{iso} [erg]	class	ref ^a
040924	0.86	0.81	$124.55^{+11.15}_{-11.15}$	$(2.28^{+0.25}_{-0.24}) \times 10^{52}$	$(1.01^{+0.05}_{-0.05}) \times 10^{52}$	misguided	(1)
050709 ^b	0.16	0.60	$97.32^{+7.76}_{-0.58}$	$(7.51^{+0.76}_{-0.81}) \times 10^{50}$	$(4.33^{+0.29}_{-0.30}) \times 10^{49}$	secure	(2)
051221	0.55	0.91	$621.69^{+87.42}_{-67.69}$	$(2.77^{+0.29}_{-0.29}) \times 10^{52}$	$(3.53^{+0.43}_{-0.31}) \times 10^{51}$	secure	(3)
061006	0.44	0.35	$954.63^{+198.39}_{-125.86}$	$(2.06^{+0.15}_{-0.31}) \times 10^{52}$	$(9.83^{+0.20}_{-0.94}) \times 10^{51}$	secure	(4)
070714B	0.92	1.04	$2150.40^{+910.39}_{-443.52}$	$(6.56^{+0.79}_{-1.36}) \times 10^{52}$	$(1.61^{+0.18}_{-0.24}) \times 10^{52}$	secure	(5)
071020	2.15	1.11	$1012.69^{+101.33}_{-101.33}$	$(3.06^{+0.35}_{-1.04}) \times 10^{53}$	$(1.24^{+0.04}_{-0.47}) \times 10^{53}$	misguided	(6)
080913	6.70	1.04	$1008.05^{+1052.52}_{-224.54}$	$(3.18^{+0.28}_{-0.50}) \times 10^{53}$	$(1.09^{+0.11}_{-0.08}) \times 10^{53}$	misguided	(7)
090423	8.26	1.30	$612.36^{+193.53}_{-193.53}$	$(4.63^{+9.95}_{-1.48}) \times 10^{53}$	$(1.17^{+1.45}_{-0.38}) \times 10^{53}$	misguided	(8)
090510	0.90	0.16	$8679.58^{+947.69}_{-947.69}$	$(1.04^{+0.24}_{-0.14}) \times 10^{54}$	$(4.54^{+1.05}_{-0.61}) \times 10^{52}$	secure	(8)
100117A	0.92	0.16	$936.96^{+297.60}_{-297.60}$	$(1.89^{+0.21}_{-0.35}) \times 10^{52}$	$(1.87^{+0.23}_{-0.23}) \times 10^{51}$	secure	(8)
100206	0.41	0.09	$638.98^{+131.21}_{-131.21}$	$(9.98^{+11.50}_{-3.25}) \times 10^{51}$	$(7.63^{+7.89}_{-2.29}) \times 10^{50}$	secure	(8)
100816A	0.81	1.11	$235.36^{+15.74}_{-15.74}$	$(9.69^{+1.95}_{-1.28}) \times 10^{51}$	$(9.03^{+1.52}_{-1.04}) \times 10^{51}$	misguided	(8)
101219A	0.72	0.35	$841.82^{+107.56}_{-82.50}$	$(1.56^{+0.24}_{-0.23}) \times 10^{52}$	$(8.81^{+1.00}_{-1.05}) \times 10^{51}$	secure	(9)

^a References for spectral parameters, peak fluxes and fluences: (1)Golenetskii et al. (2004) ; (2) Villasenor et al. (2005) ; (3) Golenetskii et al. (2005); Norris et al. (2005) ; (4) Golenetskii et al. (2006) ; (5) Ohno et al. (2007); Kodaka et al. (2007) ; (6) Golenetskii et al. (2007) ; (7) Pal’Shin et al. (2008); Stamatikos et al. (2008) ; (8) This work ; (9) Golenetskii et al. (2010).

^b 70 msec peak luminosity

LGRBs are taken from Yonetoku et al. (2010). The best fit value of A for SGRBs is different from that for LGRBs at 3- σ statistical level. This is clearly inconsistent with the conclusions of previous works (Zhang et al. 2012; Ghirlanda et al. 2009). There are some reasons why there are such difference. First of all, our peak luminosities defined uniformly by observer 64 msec resolution for all SGRBs, while Zhang et al. (2012) use different time resolutions reported by observation teams, which makes systematic dispersion in the E_p - L_p correlation (Yonetoku et al. 2010). Secondly, we use E_{iso} and L_p between 1-100,000 keV in GRB rest frame, while Zhang et al. (2012) did between 1-10,000 keV. Therefore Zhang et al. (2012) underestimates L_p . Especially for 090510 the underestimation amounts a factor ~ 0.2 . For these reasons, our E_p - L_p correlation for SGRBs seems much tighter than that of Zhang et al. (2012) and is inconsistent with the E_p - L_p correlation for LGRBs.

In this Letter, we suggested possible correlations among E_p , L_p and E_{iso} even for SGRBs. However, the correlations for SGRBs are much dimmer than those for LGRBs. The E_p - E_{iso} (E_p - L_p) correlation for SGRBs is approximately 10^{-2} (10^{-1}) times dimmer than that for LGRBs. For the E_p - L_p correlation for SGRBs, similar arguments have been made by some authors (Ghirlanda et al. 2009; Zhang et al. 2012), but we for the first time argue that there exist distinct E_p - E_{iso} and E_p - L_p correlations for SGRBs.

The distinction between SGRBs and LGRBs becomes much clearer if we use the gold sample of LGRBs compiled by Tsutsui et al. (2012). Tsutsui et al. (2012) argued that there are two E_p - L_p correlations, one is for small- $ADCL$ GRBs and the other is for large- $ADCL$ GRBs, where $ADCL$ stands for Absolute Deviations from Constant Luminosity. In figure 5, we shows the E_p - L_p diagram for small- $ADCL$ LGRBs (black filled circles), large- $ADCL$ LGRBs (blue filled triangles), and secure SGRBs (red squares). The

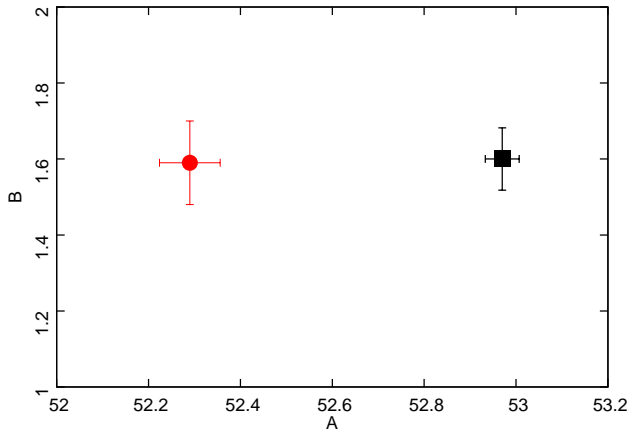


Figure 4. The best fit parameters and their 1- σ uncertainties of the E_p - L_p correlations for LGRBs (black) and SGRBs (red). We assumed the functional form $L_p = 10^A \text{ erg s}^{-1} \times (E_p/774.5 \text{ keV})^B$ and the values for LGRBs are taken from Yonetoku et al. (2010). The best fit value of A for SGRBs is different from that of for LGRBs at 3- σ statistical level.

outliers of gold sample in Tsutsui et al. (2012) and misguided SGRBs are removed from this figure. We can see the existence of three distinct E_p - L_p correlations with almost the same power law index and different amplitudes.

The accurate functional forms of E_p - E_{iso} and E_p - L_p correlation are very important to study the progenitor and the radiation mechanism of SGRBs. At present the systematic error is rather large, that is, 0.13(0.39) in logarithm for E_p - L_p (E_p - E_{iso}), respectively. This is mainly due to the small number of secure SGRBs, which prevents more detailed analysis. In conclusion we need more data of SGRBs with

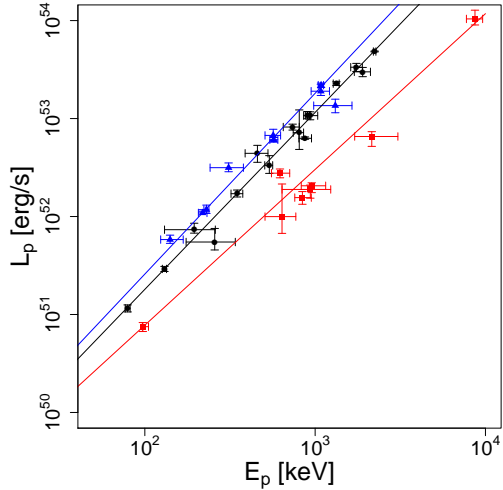


Figure 5. The $E_p - L_p$ diagram both for short and long GRBs. The LGRBs from gold sample in Tsutsui et al. (2012) are marked with black filled circles (small-ADCL GRBs) and blue filled triangles (large-ADCL GRBs). The outliers of gold sample in Tsutsui et al. (2012) and misguided GRBs are removed from this figure.

accurate z , E_p , L_p and E_{iso} to confirm or refute the $E_p - E_{\text{iso}}$ and $E_p - L_p$ correlations for SGRBs suggested in this Letter.

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